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DESIGN OF NATURAL GAS TRANSMISSION PIPELINE

(A CASE STUDY OF A TYPICAL MARGINAL OIL AND GAS FIELD IN NIGER DELTA, NIGERIA)

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ABSTRACT

The natural gas transmission pipeline for a typical marginal oil and gas field in Niger delta has been designed. A secondary data of the field gas was obtained and empirical study was carried out to determine the nature of the gas. The gas flow rate, pressure, temperature was collated and used to design the gas pipeline.

Hydraulic design equations from ASME B31.8 and API 5L standard codes and specifications were used to estimate some of the parameters used in the design. The sizing, design pressure, collapse pressure, burst pressure, hydrotest pressure. Pipe diameter, schedule number and thickness etc were calculated using appropriate design equations. Aspen HYSYS version 8.8 (34.0.0.8909) software was used to carry out simulation of the process flow and it all converged.

Keywords: Pipeline, design, Natural Gas, Marginal Field.

INTRODUCTION

Natural Gas due to its storage difficulties needs to be transported to its needed destination as soon as it is produced from the reservoir. There are a number of options for transporting natural gas energy from oil and gas fields to market (Guo Buoyan *et al*., 2005). This includes: Pipeline Natural Gas (PNG), Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Gas To Solid (GTS). Pipelines are connected pipes which are installed for the purpose of transmitting gases, liquids, slurries, etc., from sources of supply to one or more distribution center(s) or to one or more large-volume customer(s); a pipe installed to interconnect source(s) of supply to one or more distribution center(s) or to one or more large-volume customer(s); or a pipe installed to interconnect source(s) of supply. (Lyons W; 2011). Pipes are tube with a round cross section conforming to the dimensional requirements for nominal pipe size. An average of over 12,000 miles per year of newly constructed gas pipeline has been completed in the last decades; most of which are transnational. It is a common belief that if political instabilities and other variables are guaranteed, then pipelines use may be able to provide a long lasting solution for transportation of natural gas.

Marginal Field is an oil /gas field which is incapable of producing the desired net income that will trigger its development at a given point in time. However, if technical / economic conditions changes, such field may become commercially viable. It is usually associated with small pockets of hydrocarbons with a few years of plateau. Marginal fields have some issues or parameters that affects them. They include the following: Environmental concerns, political stability, access, remoteness etc. In short, marginal fields are oil and gas reserves usually too small for production to be economically viable for large oil companies. These fields are usually awarded to indigenous companies to explore, considering the size of the reserves.

Gas pipeline design is a process or plan to show the look and function of gas pipeline before it is constructed. The design consists mainly of four interrelated areas, that is, hydraulic design, mechanical design, geothermal design and operating/maintenance design (Mike Y, 2010). They are all geared towards figuring out suitable pipeline that will safely transport the fluid from the oil and gas field to the place of storage or utilization. Several codes and standards have been developed as a guide for the design, construction and operations of pipelines. The objectives of this codes and standards are to ensure the safety of the personnel and the general public by minimizing the risk of high pressure pipelines (Cult et al, 2008).

The properties and compositions of the gas must be determined in order to design an appropriate gas pipeline. Gas reservoir properties such as carbon contents, gas specific gravity, gas compressibility factor, gas viscosity, critical temperature and pressure, gas density, etc. must be determined to select the grade of the pipeline.

Pipeline route and profile survey is also required to ascertain the minimum and maximum elevation of the pipeline, to know if there will be creek/river crossing and to understand the environmental condition of such terrain.

In this paper, a case study of a typical marginal field will be undertaken to design a natural gas transmission pipeline. The terrain is fairly flat and accessible. A secondary data of the field gas will be obtained and empirical study will be carried out to determine the nature of the gas. The gas flow rate, pressure, temperature will be collated and used to design the gas pipeline.

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METHODOLOGY

Data collection and analysis for pipeline design

A secondary data of the gas sample from the field were collected for analysis as shown below.

Table 1: Gas composition

#	Compound	Mole Fraction (mole%)	Molecular Weight, g/mol
1	Methane, C_1	86.61	16.04
2	Ethane, C_2	4.46	30.07
3	Propane	2.67	44.10
4	i-Butane, i-C_4	1.88	58.12
5	n-Butane, n-C_4	1.61	58.12
6	i-Pentane, i-C_5	0.32	70.14
7	n-Pentane, n-C_5	0.16	72.15
8	Hexane, C_6	0.05	86.18
8	CO_2	2.16	44.01
9	H_2S	0.08	34.08

Gasline sales pressure, temperature and flowrate.

The flowing head pressure, temperature and flow rate from the sale line were measured with the aid of pressure gauges, temperature recorder and orifice meter respectively, and the following parameters were obtained.

- Inlet pressure = 1104 psi
- Inlet Temperature =72.4^{o}F
- Volumetric flow rate=35MSCF/D

Calculation of Gas Apparent Molecular Weight

Table 2: Gas apparent molecular weight computation

#	Compound	Mole Fraction (Y_i)	Molecular Weight, M_i, g/mol	(Y_i x M_i)
1	Methane, C_1	0.8661	16.04	13.8922
2	Ethane, C_2	0.0446	30.07	1.3411
3	Propane	0.0267	44.10	1.1775
4	i-Butane, i-C_4	0.0188	58.12	1.0927
5	n-Butane, n-C_4	0.0161	58.12	0.9357
6	i-Pentane, i-C_5	0.0032	70.14	0.2244
7	n-Pentane, n-C_5	0.0016	72.15	0.1154
8	Hexane, C_6	0.0005	86.18	0.0439
8	CO_2	0.0216	44.01	0.9506
9	H_2S	0.0008	34.08	0.0273
Total		1.0000		19.8008

Where, Y_i = mole fraction, M_i= Molecular Weight

$M_a = (Y_i \text{ x } M_i) = 19.8$g/mol
The Apparent Molecular Weight of the gas =19.8g/mol

Determination of Gas Gravity (G)

$$G = \frac{Ma}{28.9625}$$

$$G = \frac{19.8008}{28.9625} = 0.68$$

Determination of Gas Deviation Factor, Z

Calculating the pseudo-critical temperature and pressure using the following correlation.

$$\begin{aligned} Pc &= 677 + 15G - 37.5G^2 \\ &= 677 + 15(0.68) - 37.5\,(0.68)^2 \\ &= 669.86 \text{ psi} \\ Tc &= 168 + 325G - 12.5G^2 \\ &= 168 + 325(0.68) - 12.5\,(0.68)^2 \\ &= 383.22^oR \end{aligned}$$

Calculating the pseudo-reduced temperature and pressure.

$$T_r = \frac{T}{T_c} = \frac{532.2^0 R}{383.22^0 R} = 1.39$$

$$P_r = \frac{P}{P_c} = \frac{1104psi}{669.86psi} = 1.65$$

Estimating the Z factor using Katz and Standing chart
Z= f(Tpr and Ppr) = 0.88

Determination of Gas Density, ρ

$$PV = ZnRT\,; \text{ but } n = \frac{m}{Ma}$$

$$PMa = \rho ZRT$$

$$\rho = \frac{PMa}{ZRT}$$

Where, R=10.73ft^{3}psi/lbmol.^{o}R, substituting values into the above equation.

$$\rho = \frac{1104psi \times 19.8g/mol}{0.88 \times 10.73ft^3 psi/ibmol.^0 R \times 532.2\ ^0R} = 4.4\,Ib/ft^3$$

Determination of Gas Viscosity, μ

From the graph of temperature vs. molecular weight. At temperature of 72.4^{o}F and Molecular Weight of 19.9

μ_1=0.010 cp. μ/μ_1 @ (Tpr and Ppr)= 1.21

μ=1.21 x μ1= 1.21 x 0.010= 0.0121cp

Pipeline sizing

Determination of pipe diameter

Superficial velocity equation for sizing gas stream pipes is given as follows;

$$D = \sqrt{\frac{3.5 \times Qh \times TA}{PA}}$$

where D = Pipe Diameter, Q_h= Flowing Capacity (MSCF/D)
T_A = Absolute Temperature, P_A = Absolute Pressure
Where, Q_h= 35MSCF,

T_A= 72.2^{o}F + 460 =532.2^{o}F, P_A= 1104 + 14.7 =1,118.7Psia

$$D = \left[\frac{3.5 \times 35 \times 532.2}{1{,}118.7}\right]^{1/2} = 7.6''$$

7.06” + 1” allowance= 8.06”. Therefore the pipe diameter = 8 inches (152.4mm)

Determination of Pipe Nominal Thickness

The nominal wall thickness can be calculated using the Barlow’s equation.

$$t_{NOM} = \frac{P_d\, D}{2\, £_W \eta \delta_Y F_t} + C_a$$

Where;
t_{NOM}=Nominal wall thickness, mm, P_d= Design Internal pressure
C_a=Corrosion thickness allowance
$£_w$= Weld efficiency factor. It is 1.0 for seamless, Arc weld (SAW or DSAW)
δ_y= Specified Minimum Yield strength, ή= design Factor, which is 0.72 for pipeline.
F_t= Temperature derating factor, which is 1 for temperature under 250^{o}C

Let the Corrosion thickness allowance be 4.00mm

$$= \frac{1104psi \times 152.4mm}{2 \times 20{,}000psi \times 1 \times 0.72 \times 1} + 4.00mm$$

= 5.842mm + 4.00mm
= 9.84mm = 10mm

Determination of pipe schedule number.

S= 1000 x P/S
Where P= 1104 psig
S= 20,000 psig, obtained from char
:. S=1000x1104/20,000 = 55.2, Approximately, 60.
From (Nominal Pipe sizes chart), 8” nominal size, schedule 60 has a thickness of 10.33mm which is in accordance with the calculated thickness using Barlow’s equation.

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Determination of Reynolds Number and frictional factors.

$$N_{Re} = \frac{20qhG}{\mu D} = \frac{20 \times 35 \times 0.68}{0.0121 \times 8}$$

= 4,917.355

Since $N_{Re} > 2,100$. The flow is turbulent.

Determination of delivery pressure p_2, using weymouth equation.

$$Q_g = 1.1d^{2.67}\left[\frac{P1^2 - P2}{LZGT_1}\right]^{1/2}$$

Where, T_1= (72.4 +460)^{o}R,= 532.4 ^{o}R, P1= 1104psi, P2=? d= 8"-2(0.3937) =7.213"
G = 0.68, L= 14 KM = 14 x 3280.84ft= 45,931.8ft, Z = 0.88, Q_g = 35MSCF

$$35 = 8^{2.67}\left[\frac{1104^2 - P2}{45{,}931.8 \times 0.88 \times 0.68 \times 532.4}\right]^{1/2}$$

$222{,}865.5801 = 1104^{2\,-}\ P_2^2$

P_2 = 997.972 = 988Psia

Determination of gas pipeline design pressures

1. Maximum allowable pipeline operating pressure (MAOP)

MAOP = 2 x f x SMYS x t/D
= 2 x 0.72 x 60,000 Psi x 10mm/203.2mm
= 4,251.969 psi

2. Pipeline Bursting Pressure (Bp)

Bp =0.5(SMYS + SUTS)2 x t/D
= 0.5(60,000 + 75,000) 2 x 10/203.2
=8,858.2677 Psi

3. Plastic collapse pressure, Py

Py = 2 x SMYS x t/D
= 2 x 60,000 Psi x 10mm/203.2mm
= 5,905.512 Psi

4. Hydrotest pressure (H_T)

H_p =1.25 x MAOP
= 1.25 x 4,251.969 psi
= 5,314.96 Psi.

5. Pressure drop, Dp

Dp = $P_I - P_2$ =1104 – 998= 106 Psia

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Legends	Description
A	Production/Processing Base
B	Booster Station Base
X	Gas Inlet Point
Y	Gas Delivery Point
1	Ball Valve
2	Centrifugal Compressor
3	Gate Valve
4	90° Elbow
5	Centrifugal Compressor
6	Ball Valve
7	Gate Valve

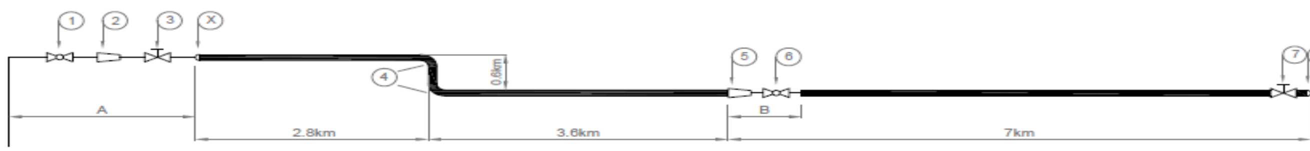

Figure 1: Schematic diagram of the Pipeline

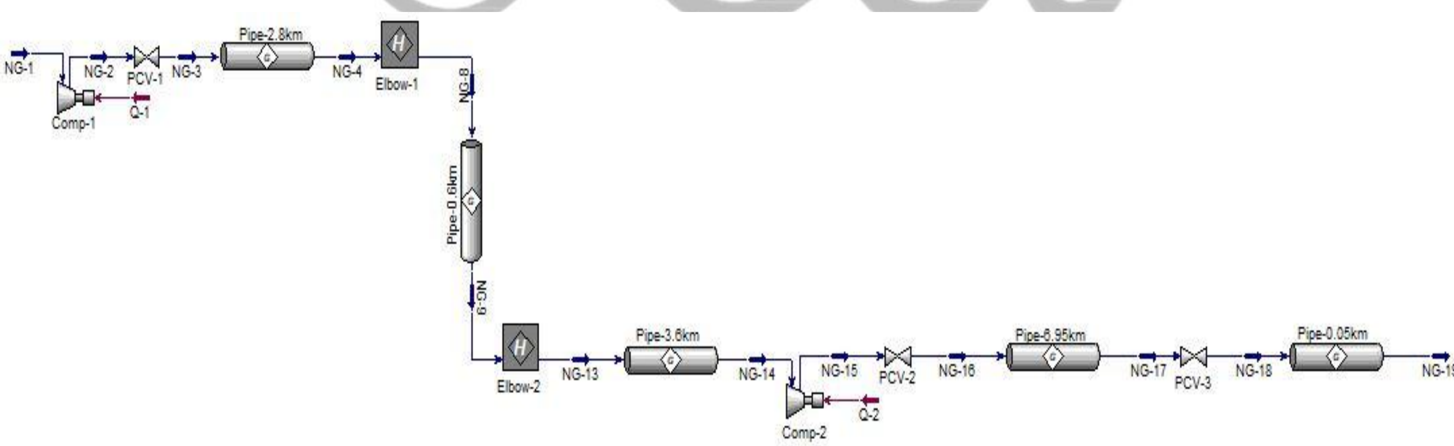

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Figure 2: Process flow diagram(PFD) of the natural gas

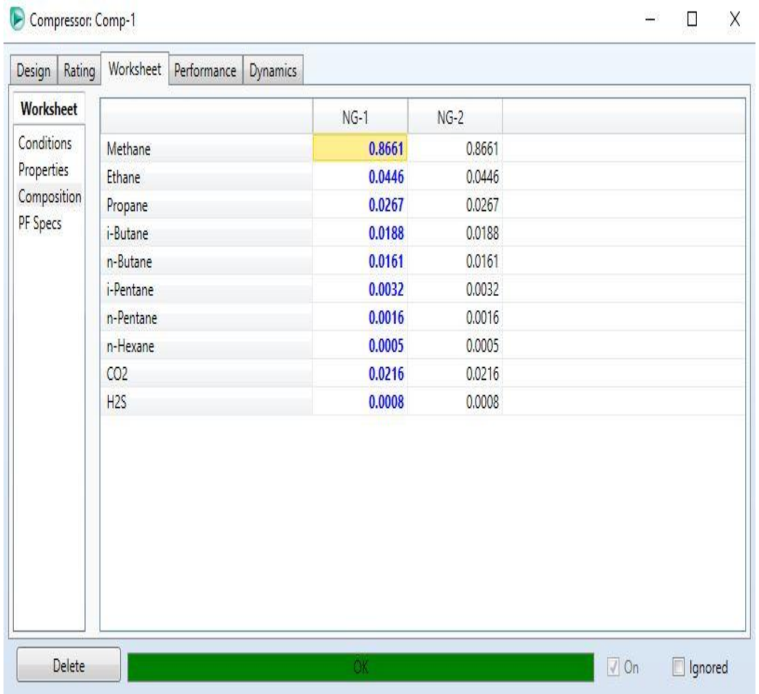
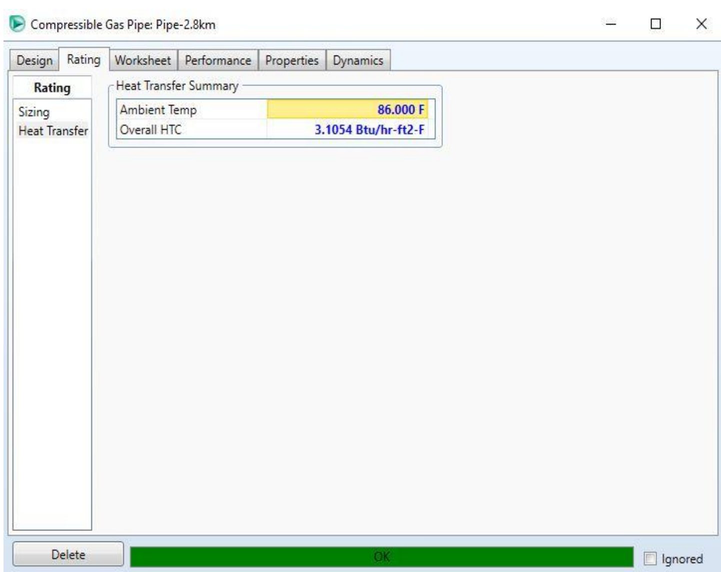


Figure 3: Composition page of the natural gas



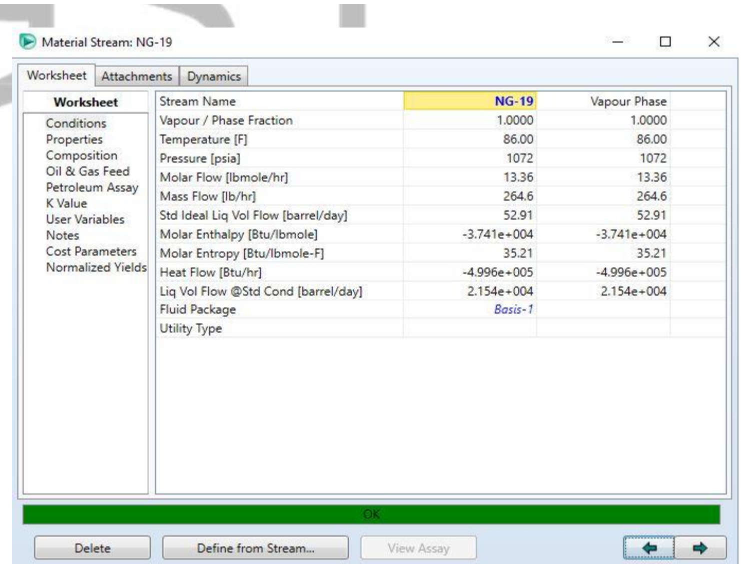
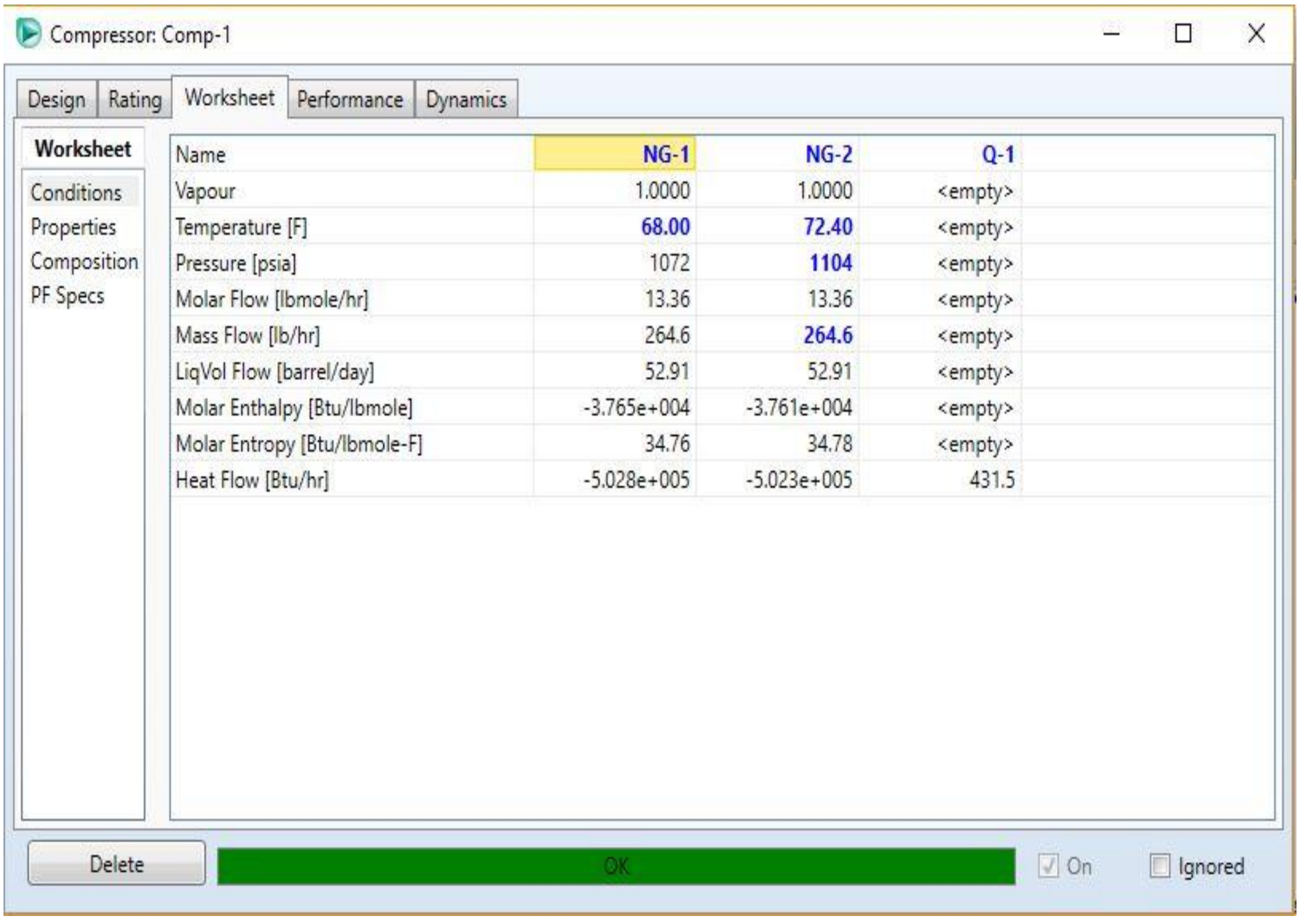


Figure 4: Heat transfer coefficient sheet **Figure5:**Nat. gas delivery condition



Compressor: Comp-1

Design | Rating | Worksheet | Performance | Dynamics

Worksheet: Conditions, Properties, Composition, PF Specs

Name	NG-1	NG-2	Q-1
Vapour	1.0000	1.0000	<empty>
Temperature [F]	68.00	72.40	<empty>
Pressure [psia]	1072	1104	<empty>
Molar Flow [lbmole/hr]	13.36	13.36	<empty>
Mass Flow [lb/hr]	264.6	264.6	<empty>
LiqVol Flow [barrel/day]	52.91	52.91	<empty>
Molar Enthalpy [Btu/lbmole]	-3.765e+004	-3.761e+004	<empty>
Molar Entropy [Btu/lbmole-F]	34.76	34.78	<empty>
Heat Flow [Btu/hr]	-5.028e+005	-5.023e+005	431.5

Delete | OK | On | Ignored

Figure 6: Initial condition sheet of the natural gas

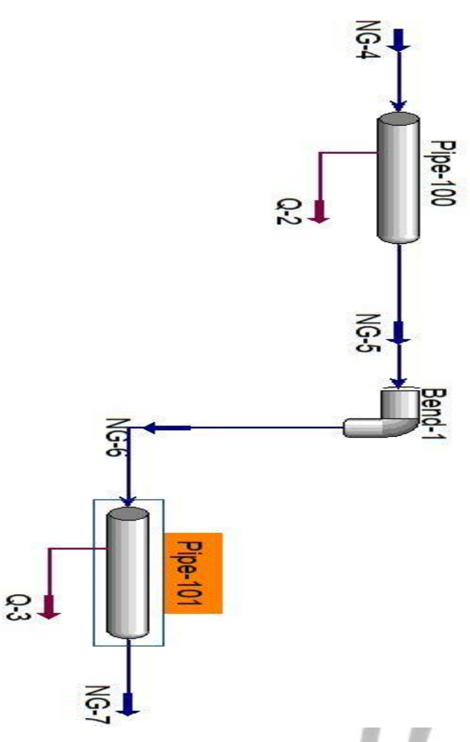


Figure 7: PFD showing First elbow

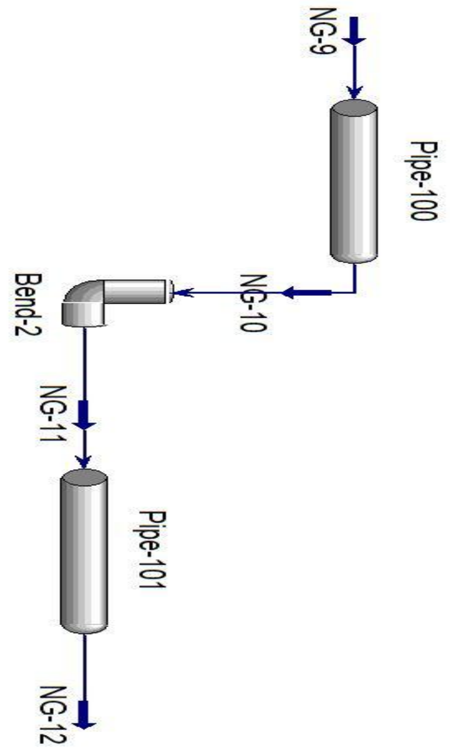


Figure 8: PFD showing second elbow

RESULT AND DISCUSSIONS

Table 3: Summary of design parameters

#	PARAMETERS	VALUE/ UNITS
1	Flow capacity, Q	35MSCF/D
2	Inlet Pressure, P1	1104 Psi (7.61 Mpa)
3	Outlet Pressure, P2	1072. Psi (7.39Mpa)
4	Inlet Temperature, T	72.4^{o}F
5	Delta (ΔP)	32psi(0.2Mpa)
6	Overall HTC	3.1054Btu/hr-ft^2.F
7	Compressor 1power consumed	3.68HP
8	Compressor 2 power consumed	3.32HP
9	Gas Molecular Weight, Ma	19.8 g/mol
10	Gas Gravity, G	0.68
11	Gas Density, ρ	4.4Ib/ft3
12	Gas Viscosity, μ	0.0121CP
13	Gas Deviation factor, Z	0.88
14	Pipe Diameter, D	8" (203.2mm)
15	Pipe Thickness, t	0.394" (10mm)
16	Pipeline length, L	8.876 miles (14KM)
17	Reynolds number, N_{Re}	4,917.355
18	Pipeline Specified Minimum Yield Strength	60,000 psi (414 Mpa)
19	Pipeline Specified Ultimate Tensile Strength	75,000 psi (517 Mpa)
20	Pipeline Maximum Allowable Operating Pressure (MAOP)	4,251.96 Psi (29.32 Mpa)
21	Pipeline Hydro test Pressure	5,314.96 Psi(36.65 Mpa)
22	Schedule number	60

The gas sample from the marginal field showed that, it is predominantly made of methane gas (C_1), the processed gas from the field is a dry gas hence, no fear for hydrate formation along the flow line. The calculated diameter is approximately 8 inches. according to ASME B31.3 pipe sizing. The pipeline wall thickness is estimated as 10mm, which is in compliance with ASME B31.8 code for 8", X-60 grade. The physical properties of the gas are gas apparent molecular weight (19.8g/mol), gas gravity (0.68), density(4.4Ib/ft^3) and viscosity(0.0121CP). In other to specify the ordering of pipes, pipe joints are produced based on their pressure rating(that is, the amount of pressure) they can withstand, termed schedule number. The schedule number is a function of the pipe wall thickness. In this research, it was calculated as 60 and from pipe size chart, 8'' nominal diameter and thickness of 10.33mm has a schedule of 60, which conformed to the calculated schedule number considering the allowable stress and operating pressures of the pipeline.

The Reynolds number which is used to predict the fluid pattern was calculated to be greater than 2100, an indication that the flow regime is turbulent. The design allowable pressure such as, the maximum allowable pressure, bursting pressure, collapse pressure and the hydro test pressure were calculated as 4,251.96, 8,858.26, 5,905.51 and 5,314.96psi respectively. The delivery pressure was calculated manually using Weymouth equation as 998psi , while the delivery pressure from the simulation is said to be 1072psi as shown in figure 5. For the purpose of precision, the simulated figure (1072psi) was considered in this design. Therefore, the pressure drop along the entire pipeline will be 32psia. Similarly, considering the Heat transfer from the steel pipe and the pipe surrounding, the overall heat transfer coefficient was determined using the simulation as 3.1054Btu/hr-ft^2.F as shown in figure 4. The coating material was assumed to be Epoxy coating of thickness of 5mm. The thermal conductivities of the steel pipe and epoxy coating are 45W/mK and 0.21W/mK respectively, as shown in table 3. The units were manually converted to W/m^{o}C so as to be consistent with the units in the software used for this design. From the full simulation report, the power consumed by the compressors at the Base Station and Booster station is said to be 3.68HP and 3.32HP respectively.

It is worthy to note that the Natural Gas Simulation processes converged. The conditions of the natural gas changes slightly as it leave each sections and fittings along the gas pipeline. For the purpose of clarity, different nomenclatures were used to represent the natural gas material streams as it enters and leaves each pipeline sections and fittings along the pipeline.

CONCLUSION

A gas transmission pipeline was designed using appropriate design equations from ASME and API codes/standard for calculating the appropriate diameter, wall thickness, schedule number, pressure ratings etc. Some of the design parameters calculated for are diameter 8", wall thickness, schedule number X-60, maximum allowable pressure, burst pressure and, delivery pressure . The gas properties and deviation factor was done using the appropriate equations. The designed pipeline was simulated using Aspen HYSYS version 8.8, and it all converged.

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